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Dente D. Poland

Stuart A. Fogel

The Johns Hopkins University
Applied Physics Laboratory
11100 Johns Hopkins Road
Laurel, MD 20723-6099 USA

R. Peter Cole

G. Steven Olmsted

Northrop Grumman Marine Systems
Hendy Avenue
Sunnyvale, CA 94088-3499 USA

LAUNCHER INTEGRATED DIAGNOSTICS DEMONSTRATION

Dente D. Poland* and Stuart A. Fogel†

The Johns Hopkins University Applied Physics Laboratory, Laurel, MD
11100 Johns Hopkins Road, Laurel, MD 20723-6099

R. Peter Cole‡ and G. Steven Olmsted§

Northrop Grumman Marine Systems
Hendy Avenue, Sunnyvale, CA 94088-3499

ABSTRACT

This paper presents the results to date of the Launcher Integrated Diagnostics Demonstration (L-IDD), which involves the development of the Launcher Integrated Diagnostics System (L-IDS) that monitors components within the Trident II Launcher Subsystem and estimates their "health." During Phase I of this project, possible monitoring areas were researched, and a prototype L-IDS was developed and tested. During Phase II, the prototype L-IDS was refined and installed on an SSBN for evaluation during deterrent patrol at sea. Launcher Subsystem equipment and the associated conditions originally investigated for monitoring included electrically actuated valves (power consumption and noise), structural components (relative position), propellants (stabilizer levels), and water-filled containers (internal corrosion). The prototype L-IDS system used the following sensors to monitor the associated equipment on the Launcher Subsystem: voltage and current sensors, and accelerometers to monitor the electrically actuated valves (i.e., variable energy ejector [VEE] valves and actuators); optical (IR) sensors to monitor the relative position of the structural components (i.e., umbilical shell and retractor stop bumper); a solid-phase micro-extraction tool to collect propellant vapor; and electrochemical sensors to monitor corrosion in a sealed container. Based on results from the prototype testing and further project resource consideration, the system being tested at sea is limited to monitoring VEE valves and actuator noise, and umbilical shell-to-retractor stop bumper relative position.

*L-IDD Project Manager

†Underwater Launch Program Manager

‡Senior Design Engineer

§Missile Launching and Handling Engineering Manager

¶Director of Industrial Capability and Assessments,
Office of Under Secretary of Defense (A&T)

#Technical Director of Strategic Systems Programs

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INTRODUCTION

This paper discusses the Launcher Integrated Diagnostics Demonstration (L-IDD), which is sponsored by Strategic Systems Programs (SSP) and is supported by Northrop Grumman Marine Systems (NGMS) and The Johns Hopkins University Applied Physics Laboratory (JHU/APL). The development and deployment of the Launcher Integrated Diagnostics System (L-IDS) and some lessons learned during this project are also discussed.

This project began in 1997 when Mr. Martin Meth¶ signed a memorandum of agreement with Captain John Stillwell. As stated in this agreement, the project objective was to demonstrate the value of using a nondestructive, nonintrusive integrated diagnostics system to monitor the Trident II Launcher Subsystem. This diagnostics system would provide decision makers with information to reduce overall maintenance costs and predict degradation of weapon system reliability.

The demonstration would also show the feasibility for the application of condition-based maintenance support for the Navy submarine maintenance community. The technical goal was to develop standard approaches for the application of submarine-integrated diagnostic systems that enhance weapon systems condition assessment capabilities. The development approach was also mandated to emphasize the integration of existing commercial off-the-shelf (COTS) hardware and software.

The project was split into two phases: Phase I culminated with the land-based testing of a Generation 1 system, and Phase II ended with the deployment of a Generation 2 L-IDS onboard a Trident II SSBN.

The Trident II Launcher Subsystem performs the following general functions within the Strategic Weapon System:

- missile vertical and lateral support,
- launch tube temperature and humidity control,
- fault monitoring, and
- launch operations, which include tube pressurization, muzzle hatch operation, and missile ejection.

L-IDD PHASE I

Phase I of the L-IDD project was completed in December 1998. During this phase, Generation 1 L-IDS was developed and tested. This effort started with a review of all potential monitoring domains (i.e., the launcher components and their associated failure modes). Engineers and analysts from the Trident II Launcher Subsystem prime contractor (i.e., NGMS) and system analysts (i.e., JHU/APL) who are experienced with the analysis of the system were used in this effort. There were no limits or constraints (i.e., cost or technical feasibility) on selecting these domains. This portion of Phase I ended with the generation of a component/failure matrix.

Phase I continued with the formation of Domain Teams and a System Architecture Team. A Domain Team comprised a domain expert, a sensor engineer, and a software engineer. The System Architecture Team consisted of several data acquisition and network system experts.

During monitoring concept development, each member of the Domain Team worked together to produce a domain-monitoring concept. The domain expert had direct knowledge of the component function and its failure mode(s). Together, the domain expert and the sensor engineer investigated COTS sensor technologies that were applicable to the component and its failure mode(s). Once candidate sensor(s) were selected, the domain expert worked with the software engineer to produce diagnostic and prognostic software to analyze the sensor data.

The Architecture Team was supplied with the data transfer and recording requirements for each domain. With this information, the team developed concepts for the L-IDS data acquisition system and processor. Once a monitoring concept was developed, a cost analysis was performed using true or estimated costs and benefits. If the cost analysis was not favorable and could not be made favorable by changes to the domain-monitoring concept, then the domain concept was dropped from the project. If the cost analysis was favorable, then the technical feasibility of the design concept was further evaluated. Technical feasibility was mainly judged on whether the sensor(s) or system would adversely affect the Strategic Weapon System (SWS). Monitoring concepts that were found to have a high probability of adversely affecting SWS reliability were eliminated.

Next in Phase I, the remaining monitoring concepts and a selected architecture were finalized, and all hardware was purchased. Generation 1 L-IDS was produced and bench-top tested for evaluation. The domains included were the following:

- Position monitoring—an optical position sensor is used to monitor the relative position of two components that are critical to the successful launch of the missile.

- Valve performance monitoring—accelerometers are used to monitor the performance of electrically actuated valves, which are directly connected to the SSBN hull and are periodically activated during patrol operations.
- Propellant degradation monitoring—a portable chemical sampler is used to collect a vapor sample from inside the Trident II gas generator. This sample is analyzed to determine stabilizer levels.
- Component corrosion monitoring—corrosion sensors measuring electrostatic potential are used to monitor active pitting corrosion within a sealed chamber that is filled with water.
- Elastomeric degradation monitoring—linear voltage differential transducers and accelerometers are used to monitor elastomeric mount performance. These mounts function to vertically support the missile and dampen vertical shock.

Portions of Generation 1 L-IDS were tested during a land-based demonstration of the system. During this demonstration, the sensors monitored actual Trident II Launcher Subsystem components in the vendor's evaluation laboratory. This test ended in December 1998.

L-IDD PHASE II

Phase II of the L-IDD project is in progress; it started with a detailed evaluation of the land-based demonstration test results from Phase I. The test results were used for a Final Design Review, which included both cost and technical feasibility assessments. Four monitoring concepts were tested during the land-based test, and of those four, two remained following the Final Design Review. Position and valve monitoring sensors using COTS or modified COTS components were demonstrated to be both cost effective and technically feasible. Another finding of the land-based test was that the L-IDS architecture was not sufficiently robust. Following the Design Review, the architecture design was replaced with a more robust and less expensive architecture. This system is referred to as Generation 2 L-IDS.

Once Generation 2 L-IDS was defined, a Temporary Ship Alteration (TEMPALT) Package and Special Test Plan were developed. The TEMPALT defines the location of the equipment on the SSBN and other pertinent information concerning the effect of L-IDS on the SSBN and its crew. The Special Test Plan governs the performance of the test onboard the SSBN.

All of the equipment was again tested at the vendor's evaluation laboratory to demonstrate that:

- it functioned properly when assembled into a single system,
- L-IDS was not adversely affected by the operation of the monitored equipment,

- the monitored equipment was not adversely affected by L-IDS, and
- all operating instructions were correct.

Results from this test were excellent and all test objectives were met.

L-IDS was shipped to the Trident Training Facility in Kings Bay, Georgia, for a final fit and operational check to ensure that the equipment functioned after shipment and prior to installation. The Trident Launcher Training Laboratory, which contains a tactically representative single launch tube, was used for this test. The equipment was installed and checked for proper operation. The test results were again excellent and the equipment was packaged for storage. L-IDS was successfully installed on an SSBN and preliminary results showed proper operation of the system. Performance analysis will be performed periodically. Generation 2 L-IDS domain monitoring will be discussed in the next two subsections.

Position Monitoring

The L-IDS position-monitoring sensor tracks the relative position of two components whose alignment is critical for proper launch performance: the umbilical plug and stop bumper (Figure 1). Each Trident II missile is connected with two umbilical plugs, which provide electrical signals and cooling water to the missile in the tube prior to launch. During launch, as the missile begins to move upward, the umbilical plugs must be disconnected and then removed from the missile's path. As the missile and umbilical plugs begin to move upward, the umbilical plugs each contact a "stop bumper." The stop bumper inhibits further upward travel of the plug and disconnects the plug from the missile; it is removed from the missile's path by a gas-activated mechanical retractor.

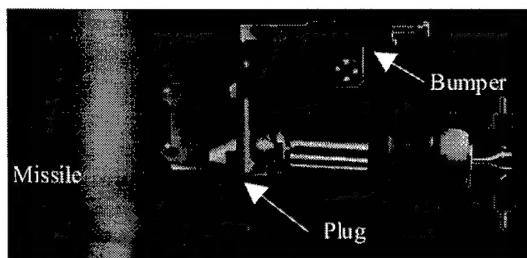


Figure 1. Missile umbilical plug and stop bumper

Proper alignment of the umbilical plug and the stop bumper is variable and critical, and is manually set after the missile is loaded. Once the alignment is set (properly or not), it is not regularly accessible for verification. Therefore, any changes in the component positions are not currently monitored.

The L-IDS position-monitoring sensor uses infrared light to track small reflective spots that are attached to the umbilical plug and stop bumper. The coordinates of components are sent via the data acquisition system to the processor for storage and analysis.

Valve Monitoring

During SSBN missile launches, valves are used to meter water into gas generator rocket motor exhaust to push the missile out of the submarine; by controlling the amount of water in the exhaust, the energy imparted to the missile can be controlled. These valves are directly connected to the SSBN hull and the amount of noise they produce is a concern. It has also been determined that valve cycling time is related to valve performance. These valves are exercised several times a month during normal SSBN operations.

Accelerometers are used to monitor valve noise and valve cycling time. These data are sent via the data acquisition system to the processor for storage and analysis.

L-IDS Architecture

All of the L-IDS equipment is located within the missile compartment of the selected SSBN. L-IDS monitors the umbilical plugs and stop bumper for one tube (i.e., two plug and stop bumper sets) and the eject system valves for two tubes (i.e., 10 valves). All of the data acquisition and processor components are mounted in the foundations of existing electronic cabinets, and system power is supplied from nonvital power panels.

The TEMPALT is valid for the 12-month period following installation. L-IDS performance is being assessed every several months, and based on its performance, several options will be entertained. If L-IDS is successful in providing useful information, a TEMPALT extension will be sought, which will allow for further performance assessment.

LESSONS LEARNED

Overall, the L-IDS project proved difficult to complete successfully. Some of the difficulties are discussed below.

Safety

Both crew and ship safety is of paramount concern to the Navy. L-IDS was designed to monitor the Launcher Subsystem for a ballistic missile weapon system, which is governed by very strict nuclear safety rules and guidelines. The design of L-IDS, therefore, was constrained by crew, ship, and nuclear safety regulations. Often throughout the L-IDS design progress, domains were modified or eliminated due to nuclear safety concerns. Had nuclear

safety not been a major factor in the Launcher Subsystem, other domains would have been successfully developed for implementation into L-IDS. Nuclear safety was the strictest filter of potential L-IDS monitoring domains.

Coordination

Each part or space on a Trident submarine is under the responsibility of an organization (i.e., under its coordination). Sometimes coordinating between these organizations is difficult and costly. Some potential L-IDS design solutions could only be possible with the involvement of organizations other than NGMS; therefore, if a particular organization was not participating in the project, funding for the design solution was not available. Consequently, alternate and normally less desirable solutions were implemented or the domain was eliminated from consideration.

Legacy System

Another area that proved difficult for the design of L-IDS was the legacy of the Launcher Subsystem itself. Components could not be monitored due to the physical constraints of the existing system (e.g., a sensor was too big to access an area). Also, access to certain locations was not feasible due to nuclear safety concerns, and further domain development was stopped. These areas could have been monitored only by implementing the sensors or their access at the time of legacy system production.

Cost-Benefit Analyses

Several monitoring types were dropped due to their lack of benefit. The failure symptoms could be monitored and diagnosed; however, the cost of implementing a monitoring system for these symptoms outweighed the potential benefit.

COTS

L-IDS was produced using COTS or modified COTS sensors and data acquisition equipment. During Phase I, many different sensor technologies were investigated for implementation into L-IDS. One major lesson learned was that the intended use of the COTS sensor is not its only application. For example, the position-monitoring sensor now tracks the position of two reflective targets; however, its intended use was as a computer mouse or pointer for people without use of their hands.

Modifications to the position sensor were required; however, the cost was well within the benefit gained from monitoring the component positions. The sensor was modified and tested for both electromagnetic interference and shock military standards. These modifications were time consuming and involved a certain amount of risk (i.e., we did not know if the modifications would satisfy the requirements). Although the modifications to the sensor were successful in this case, some modified COTS components may not provide sufficient benefit owing to their military requirements.

Also, many processor choices available in today's market quickly become antiquated. During L-IDS development, both PC and Versa Module Eurocard (VME) architectures were investigated. VME is the current wave; however, both have their benefits. Much research was performed to determine the best platform for this demonstration. In this case, the decision was ultimately driven by cost; therefore, a PC processor and accompanying data acquisition were selected for a fraction of the VME cost.

Architecture Change

The initial PC architecture relied on an Ethernet data acquisition system with a stand-alone processor. During the first land-based test, this architecture was found to be very unreliable and was scrapped during subsequent design refinement. A portable data acquisition system was selected for L-IDS implementation. Its performance was far superior to the previous Ethernet system and was purchased for a much lower total cost. Although software revision was required when the switch was made, this effort was insignificant when compared to the scope of the project.

Integrated Diagnostics

Foresight, including integrated diagnostics development, should be emphasized during weapon system development.

SUMMARY

An integrated diagnostics system was developed using COTS items and was implemented on an SSBN. L-IDS will monitor Trident II Launcher Subsystem equipment over the next year and its performance will be periodically accessed. Follow-on effort could involve an expanded L-IDS demonstration.



DEPARTMENT OF THE NAVY

STRATEGIC SYSTEMS PROGRAMS
3801 NEBRASKA AVENUE NW
WASHINGTON DC 20393-5443

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From: Director, Strategic Systems Programs
To: Director, The Johns Hopkins University, Applied Physics
Laboratory, (Attn: T. A. Mattes), 11000 Johns Hopkins
Road, Laurel, MD 20783-6099

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